D0 Results on Diphoton Direct Production and Photon + 3 Jet Double Parton Interactions

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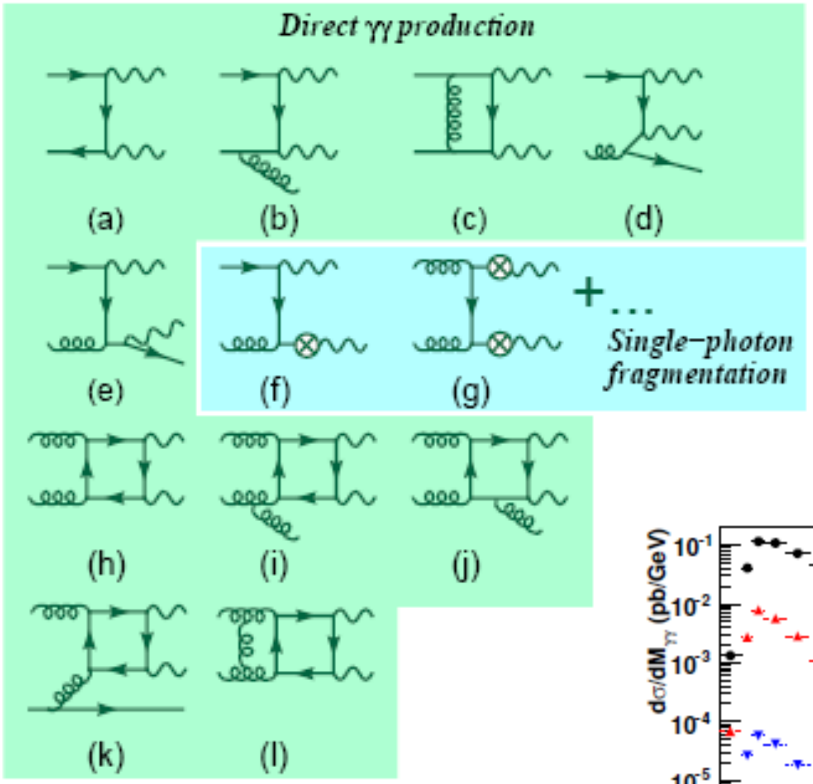
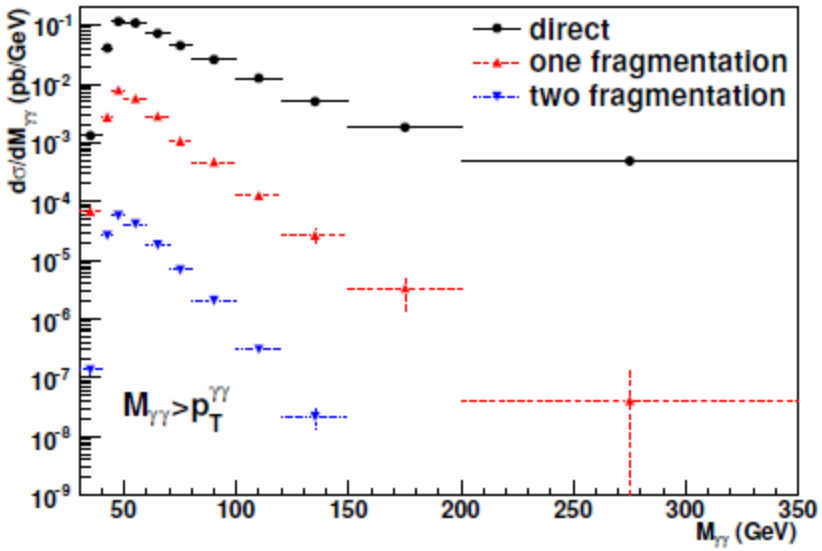
Shedding Light on QCD



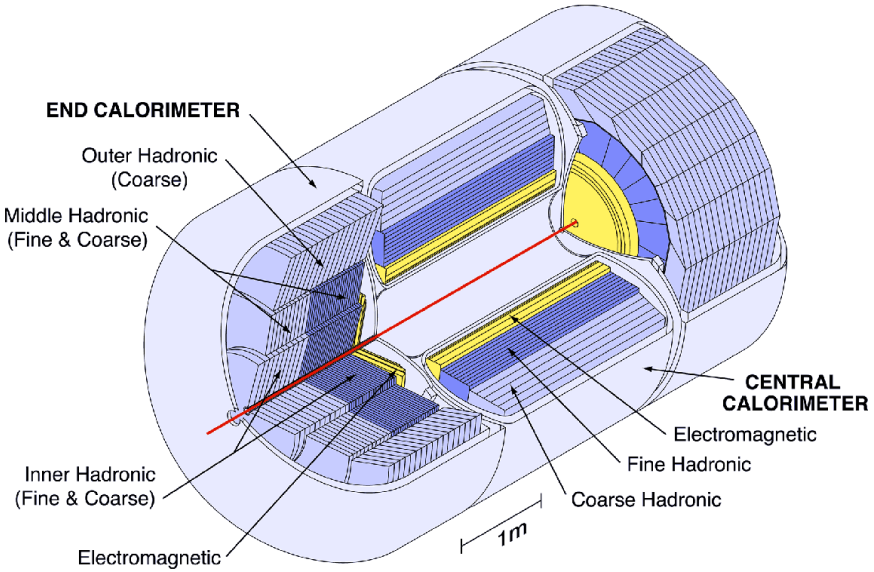
- Important test of pQCD
  - Soft gluon resummation
- Major background to H→γγ
- Classes of Production
  - Direct *(a-e & h-i)*
    - "Born & Box" diagrams
  - Single Fragmentation *(f)*
  - Double Fragmentation *(g)*

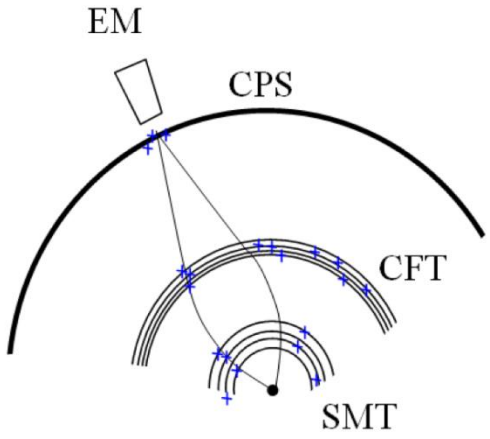


Graphs from PRD 76 013009 (2007)
Plots from DIPHOX

Finding a Photon

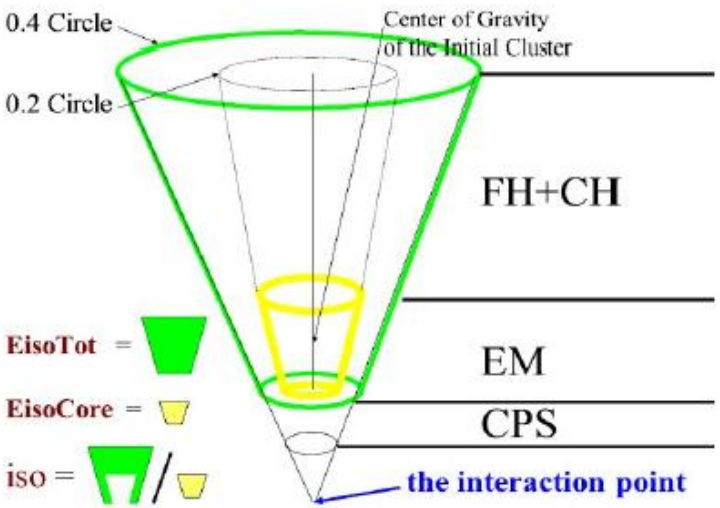
- D0 Electromagnetic Calorimeter
  - Approx 20 radiation lengths thick
  - Coverage $|\eta| < 1.1$ & $1.5 < |\eta| < 3.2$
  - $\Delta\eta x \Delta\phi = 0.1x0.1$ (0.05x0.05 at shower max)
- High precision tracking
  - Silicon microstrip tracker
  - Central fiber tracker
  - Central & forward preshower detectors

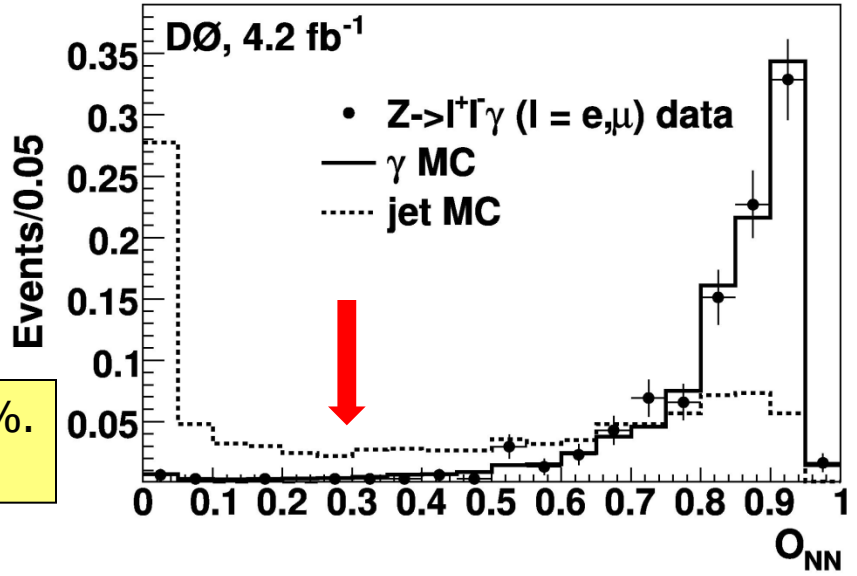




Finding a Photon

- Central photons are selected from EM clusters reconstructed within a cone with radius R=0.2 requiring:
  - High EM fraction: >97%
  - Isolated in the calorimeter
  - Isolated in the tracker
  - Shower width in 3rd EM layer consistent with an EM object.
- Photon purity is further improved by using an Artificial Neural Net (ANN) for identification
- Inputs:
  - Tracker isolation
  - Number of EM1 cells within R<0.2
  - Number of EM1 cells within 0.2<R<0.4
  - Number CPS clusters within R<0.1
  - Squared-energy-weighted width of energy deposition in the CPS





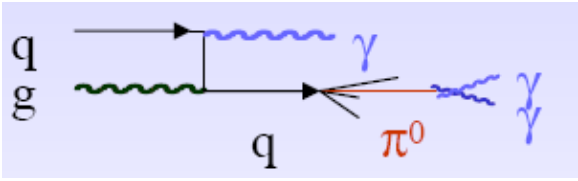
Photon efficiency: 98%. Systematic uncertainty 1.5%.
Rejects ~40% of misidentified jets.

Direct Diphotons

"Measurement of direct photon pair production cross sections in $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV", V. Abazov, et al. (Submitted to Phys. Lett. B, arXiv.org:1002.4917)

- In 4.2 fb-1 of data collected with a variety of di-EM triggers
  - Trigger efficiency after offline selection is ~100%
- Require
  - 2 photons with p_T>21(20) GeV, $|\eta|$<0.9, E_T^{iso}<2.5 GeV
  - $\Delta R(\gamma,\gamma)>0.4$
  - $p_T(\gamma\gamma)<M(\gamma\gamma)$
- Primary vertex with highest number of tracks required to have $|z_{PV}|$<60 cm.
  - Photon kinematics computed with respect to this vertex.
- Results compared to RESBOS, DIPHOX, PYTHIA
  - See talk by Steffen Schumann at the MC4LHC Workshop for comparisons to SHERPA

$$E_T^{iso} = \sum_{\substack{\text{partons or hadrons} \\ \text{within } \Delta R<0.4}} p_{T,i} - p_{T\gamma}$$



$$\frac{d\sigma}{dX} = \frac{N_{\gamma\gamma}}{\varepsilon \cdot A \cdot L \cdot \Delta X} \; ; X = M_{\gamma\gamma}, p_T^{\gamma\gamma}, \Delta\phi_{\gamma\gamma}, |\cos\theta^*|$$

Estimated number of prompt diphoton events

Bin width

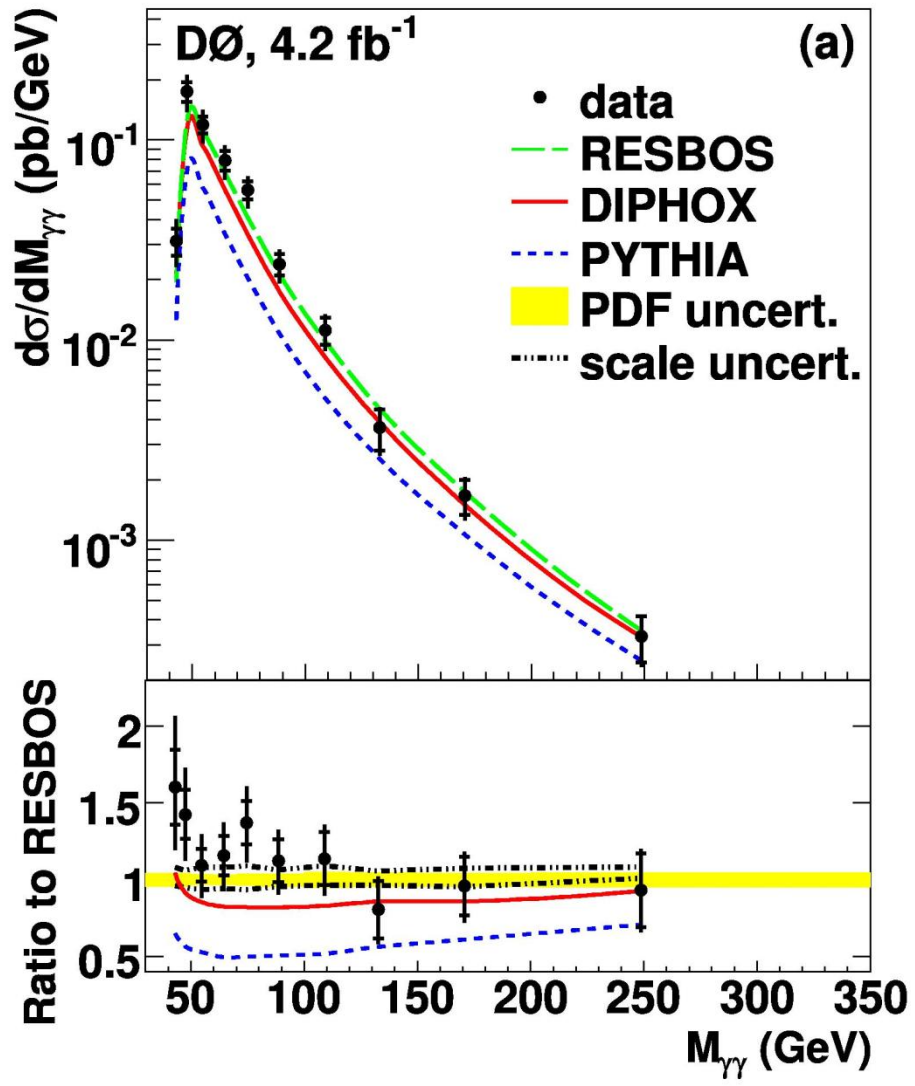
Event selection efficiency

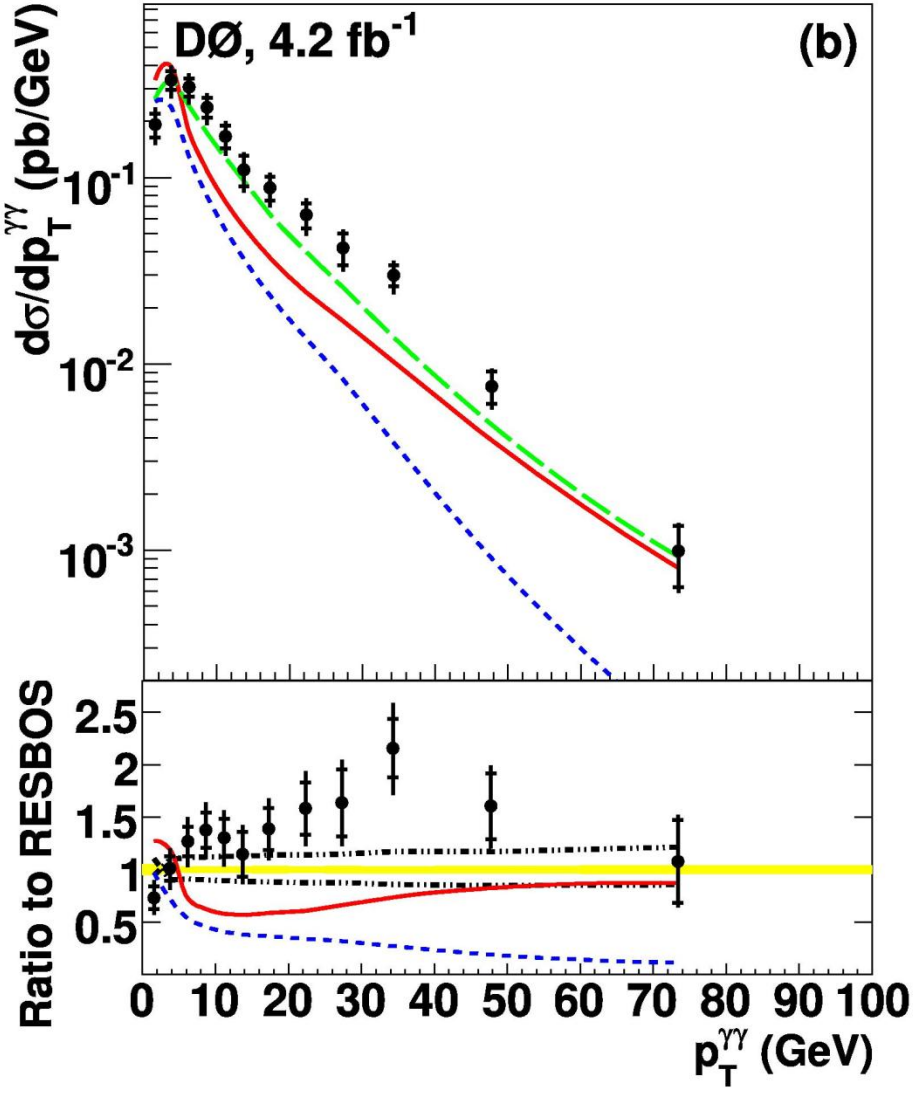
Integrated luminosity

Event acceptance

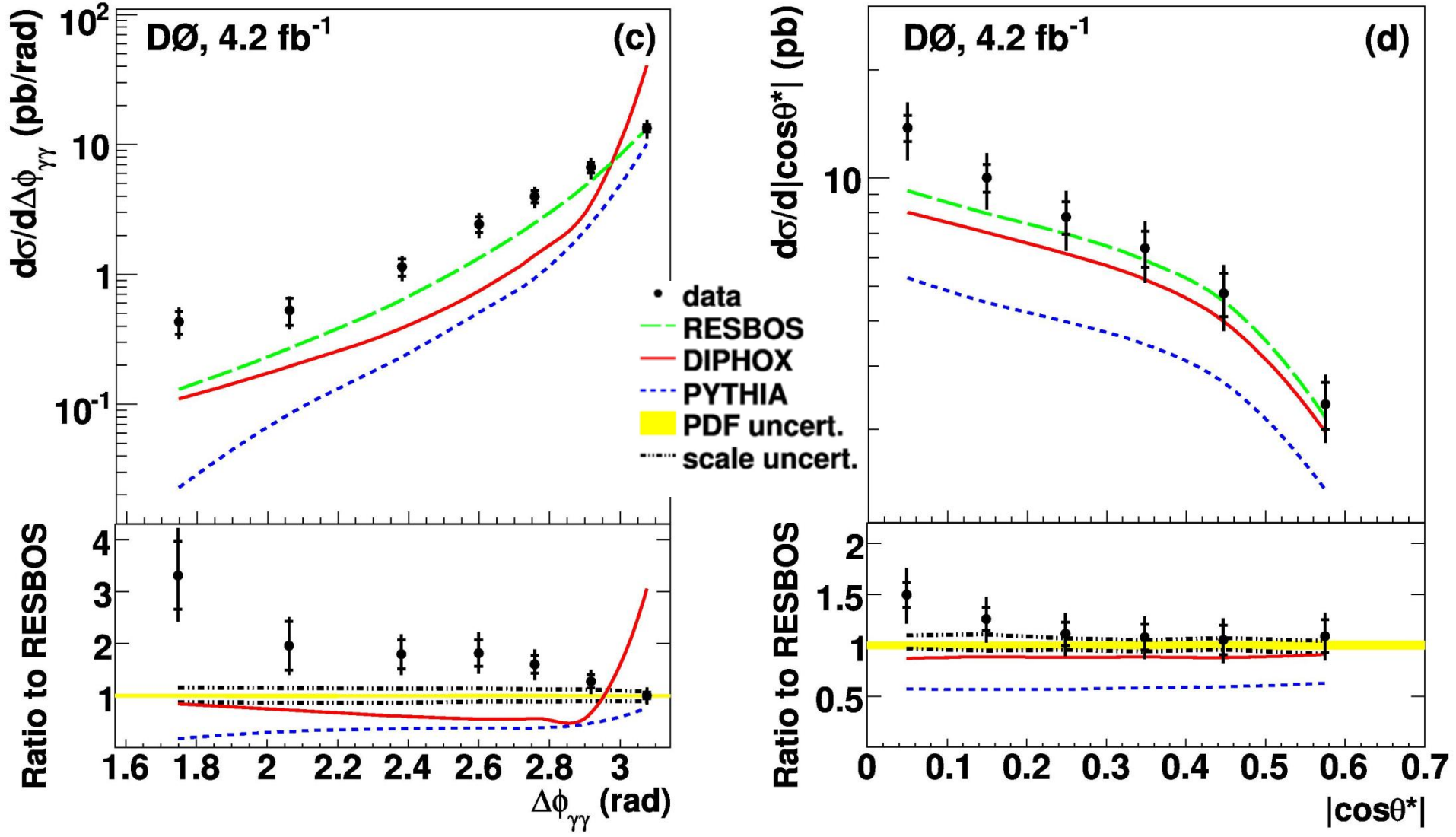
DATA	10938
γγ	7307 +/- 312
γ+jet	1791+/- 411
Dijet	1679+/- 281
Z/γ* ->ee	161+/- 10

Single Differential Cross-Sections



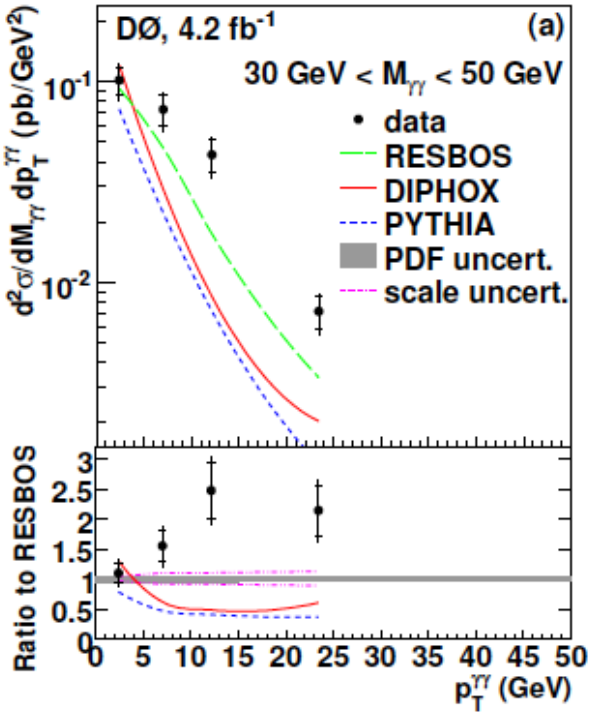


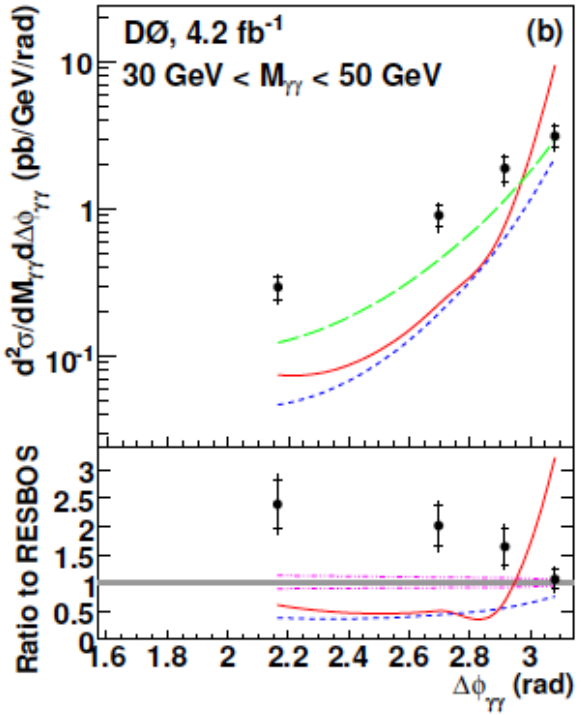
Single Differential Cross-Sections

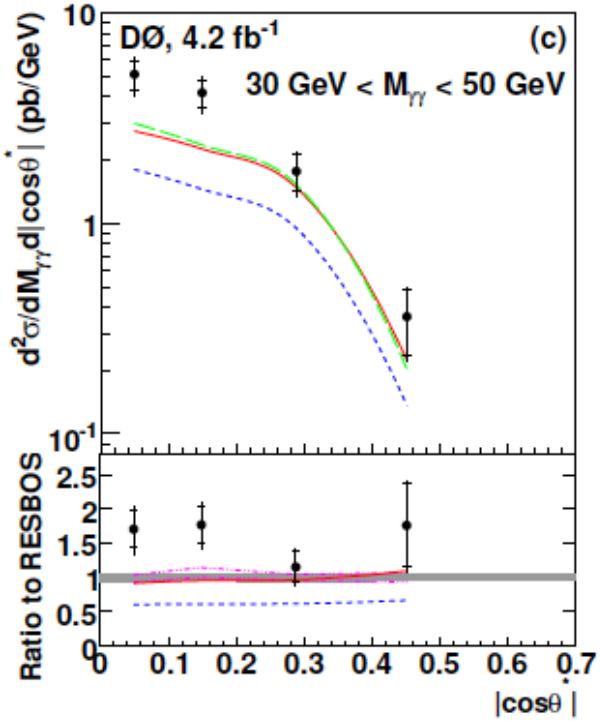


Double Differential Cross-Sections

30 < Mγγ < 50 GeV

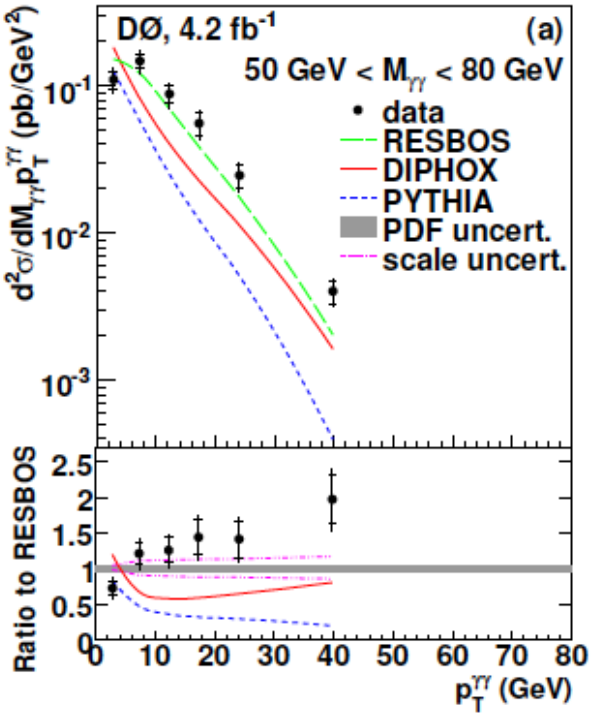


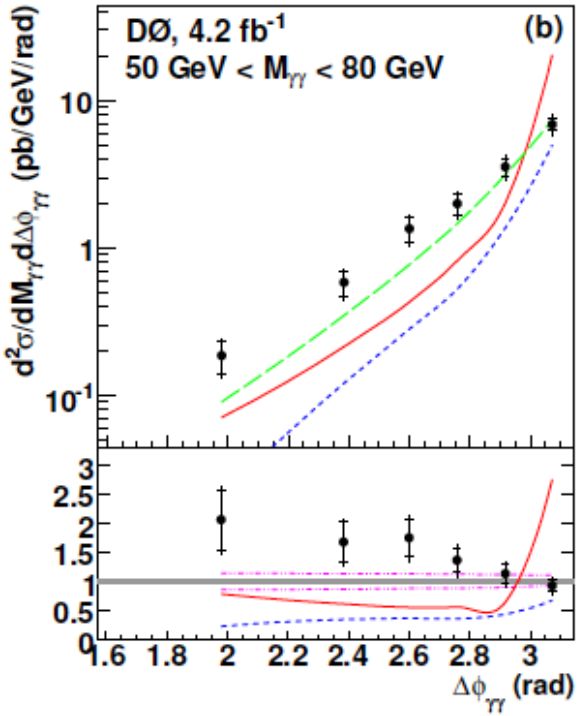


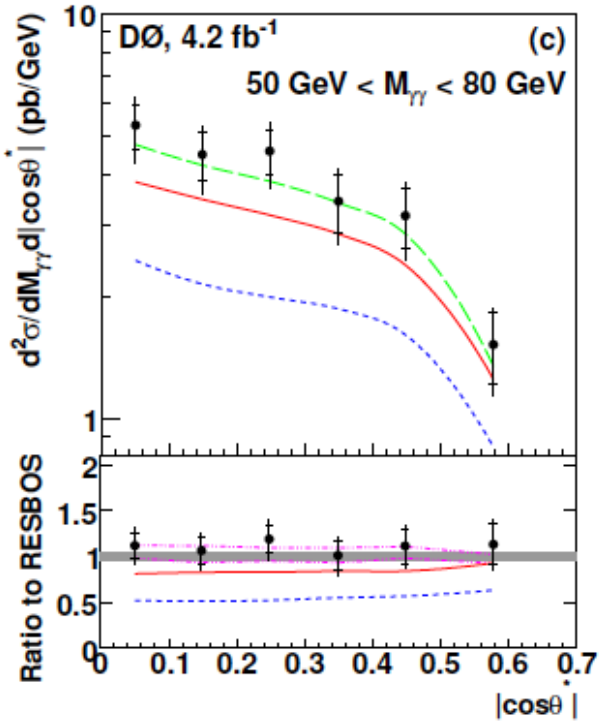


Double Differential Cross-Sections

50 < Mγγ < 80 GeV

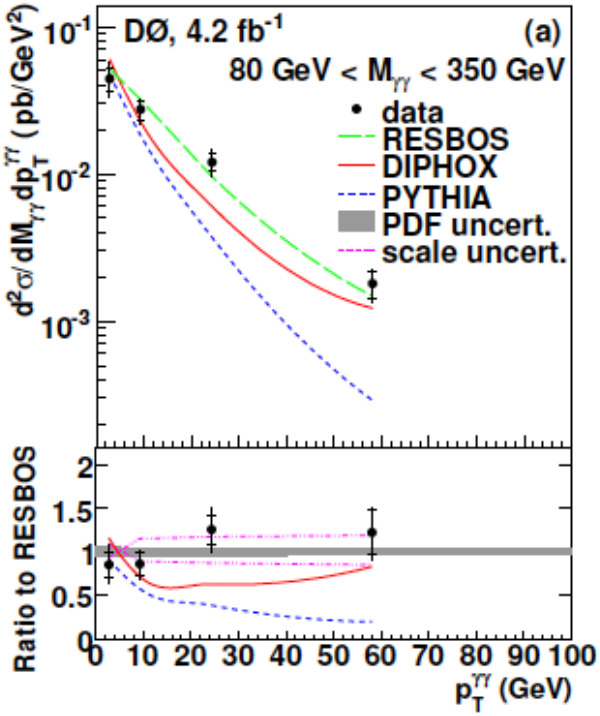


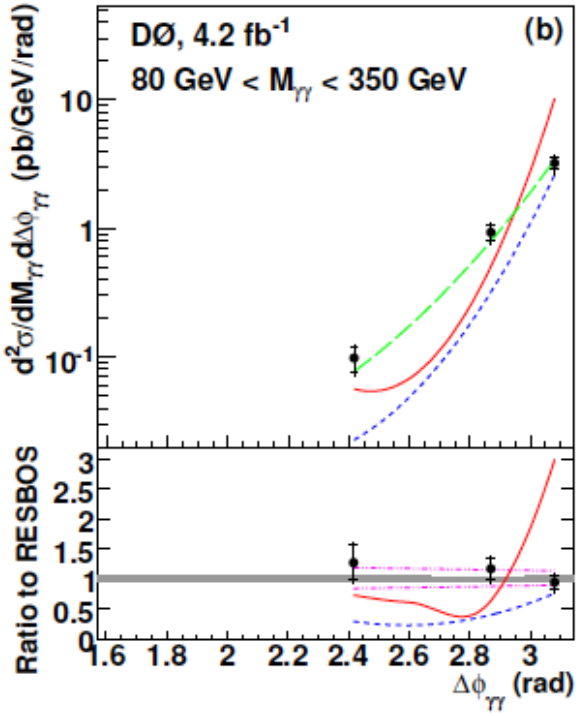


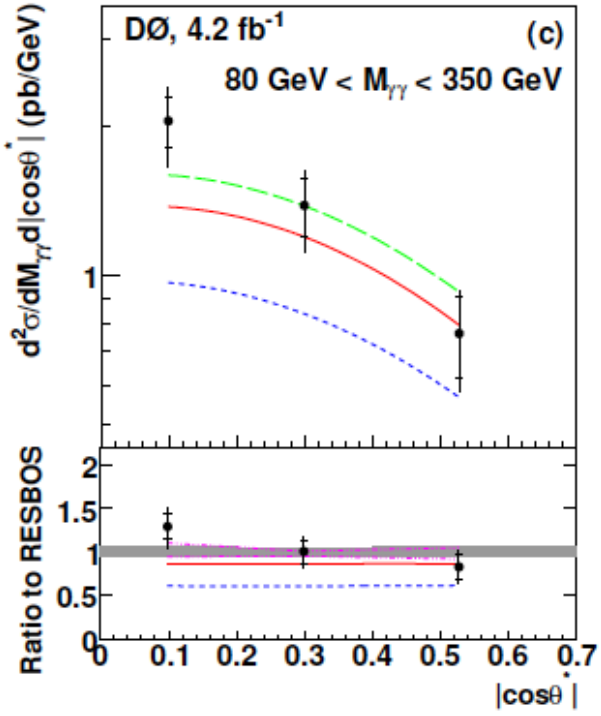


Double Differential Cross-Sections

80 < Mγγ < 350 GeV

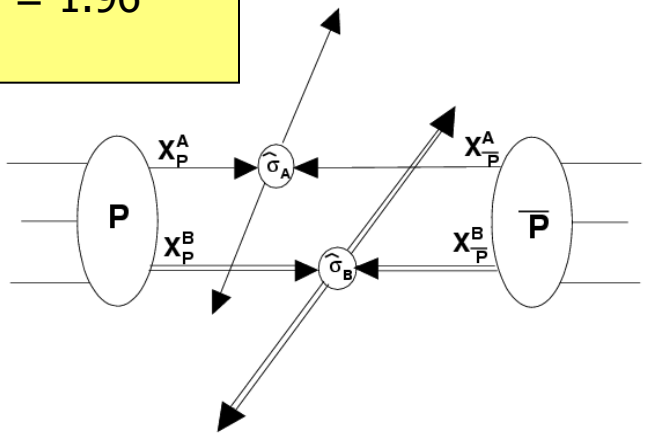






Double Parton Interactions

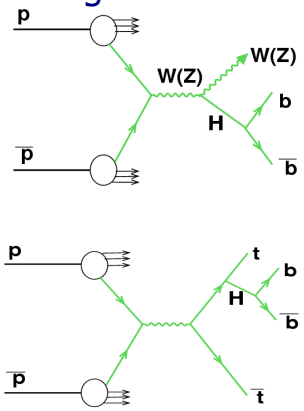
"Double parton interactions γ+3 jet events in pp collisions at $\sqrt{s}$ = 1.96 TeV", V. Abazov, et al. Phys. Rev. D **81**, 052012 (2010)



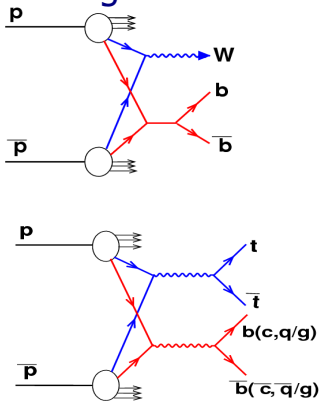
- Provides insight into parton spatial distributions
  - May impact PDFs
- Double Parton cross-section given on a scaling parameter σ_{eff}
  - Large values → Uniform spatial distribution
- Double Parton interaction can be background to several important rare channels, including Higgs searches

$$\sigma_{DP} = \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

Signal

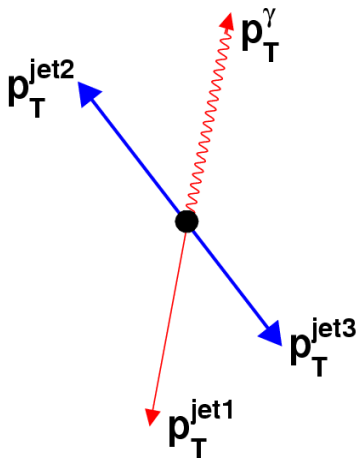


DP background

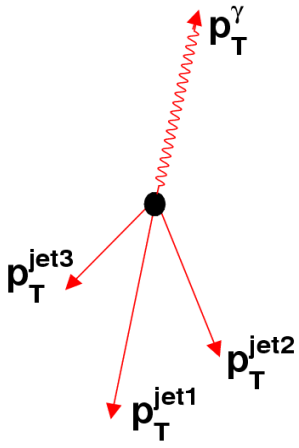


γ+3 Jets DP Topology

Double Parton



Single Parton



Signal: Double Parton (DP) production:
1st parton process produces γ-jet pair,
while 2nd process produces dijet pair.

Background: Single Parton (SP) production:
single hard γ-jet scattering with 2 radiation jets in 1vertex events.

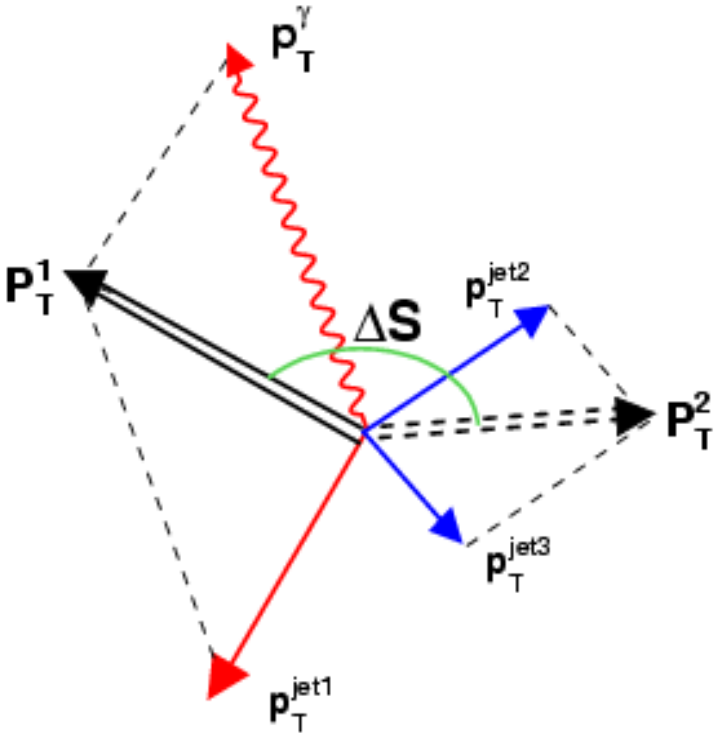
Discriminating Variables

$$\Delta S = \Delta\phi(p_T^{\gamma,\,\mathrm{jet}}, p_T^{\mathrm{jet}_i,\,\mathrm{jet}_k})$$

- $\Delta\phi$ angle between two best pT-balancing pairs
- The pairs should correspond to a minimum ΔS value:

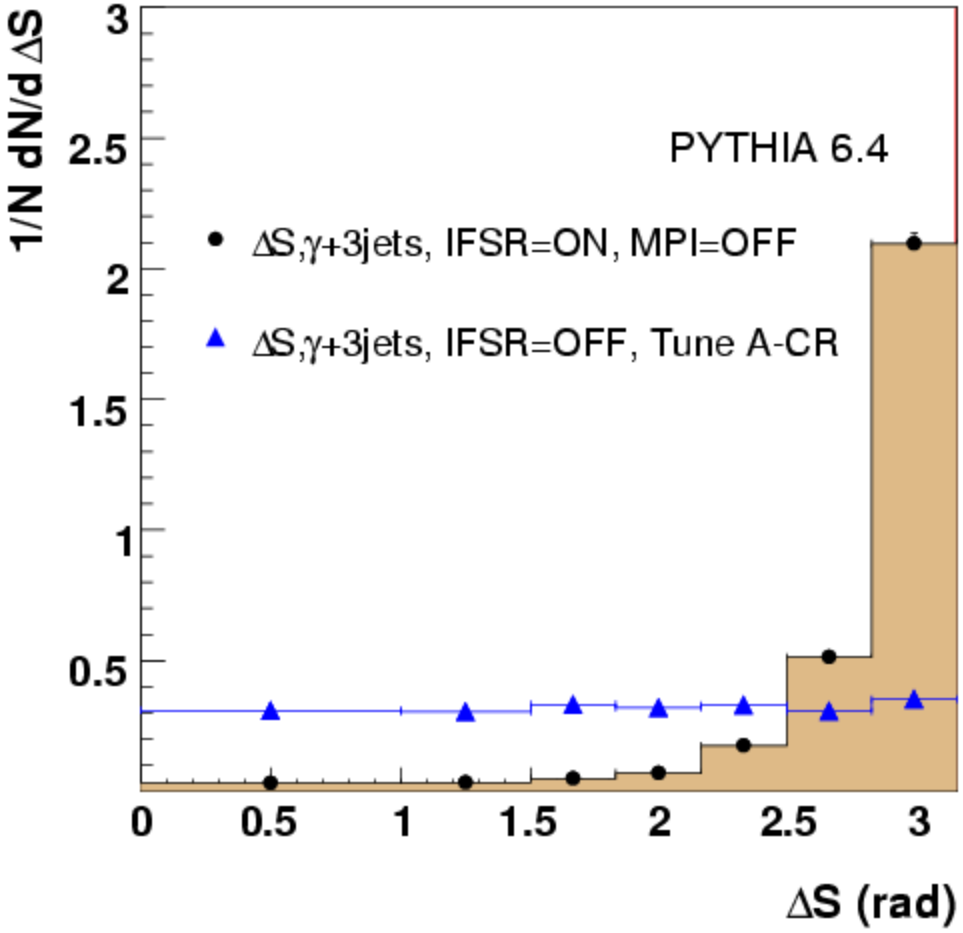
$$S_\phi = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{\Delta\phi(\gamma,i)}{\delta\phi(\gamma,i)}\right)^2 + \left(\frac{\Delta\phi(j,k)}{\delta\phi(j,k)}\right)^2}$$

$$S_{pT} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|\vec{P_T}(\gamma,i)|}{\delta P_T(\gamma,i)}\right)^2 + \left(\frac{|\vec{P_T}(j,k)|}{\delta P_T(j,k)}\right)^2}$$



In the signal sample most likely (>94%) S-variables are minimized by pairing photon with the leading jet.

Single Parton ΔS: γ+3-Jets

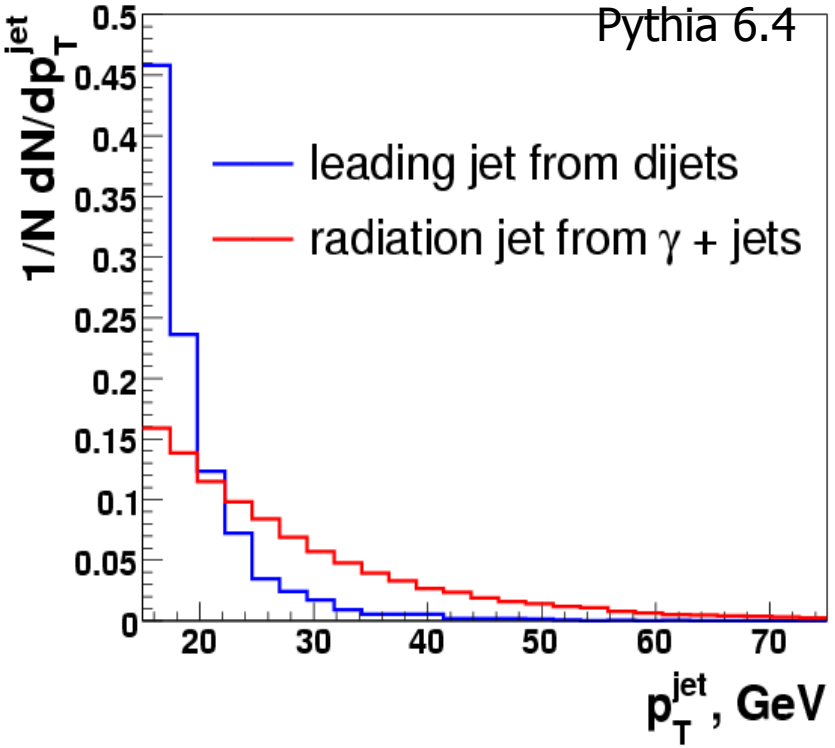


➔ For "γ+3jets" events from Single Parton scattering we expect ΔS to peak at π,

Should be flat for "ideal" DP interaction
(2^{nd} and 3^{rd} jets are from dijet production).

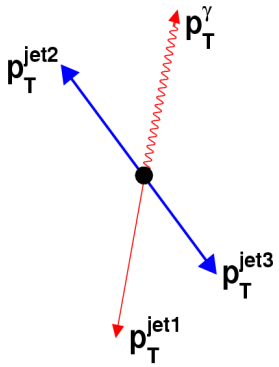
P_T Binning: Motivation

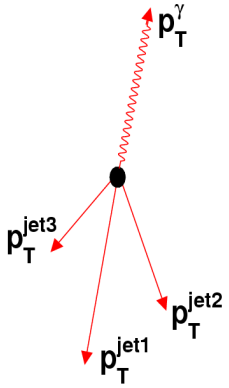
Jet P_T: jet from dijets vs. radiation jet from γ+jet events



$\sim 1 / p_T^4$

$\sim 1 / p_T^2$

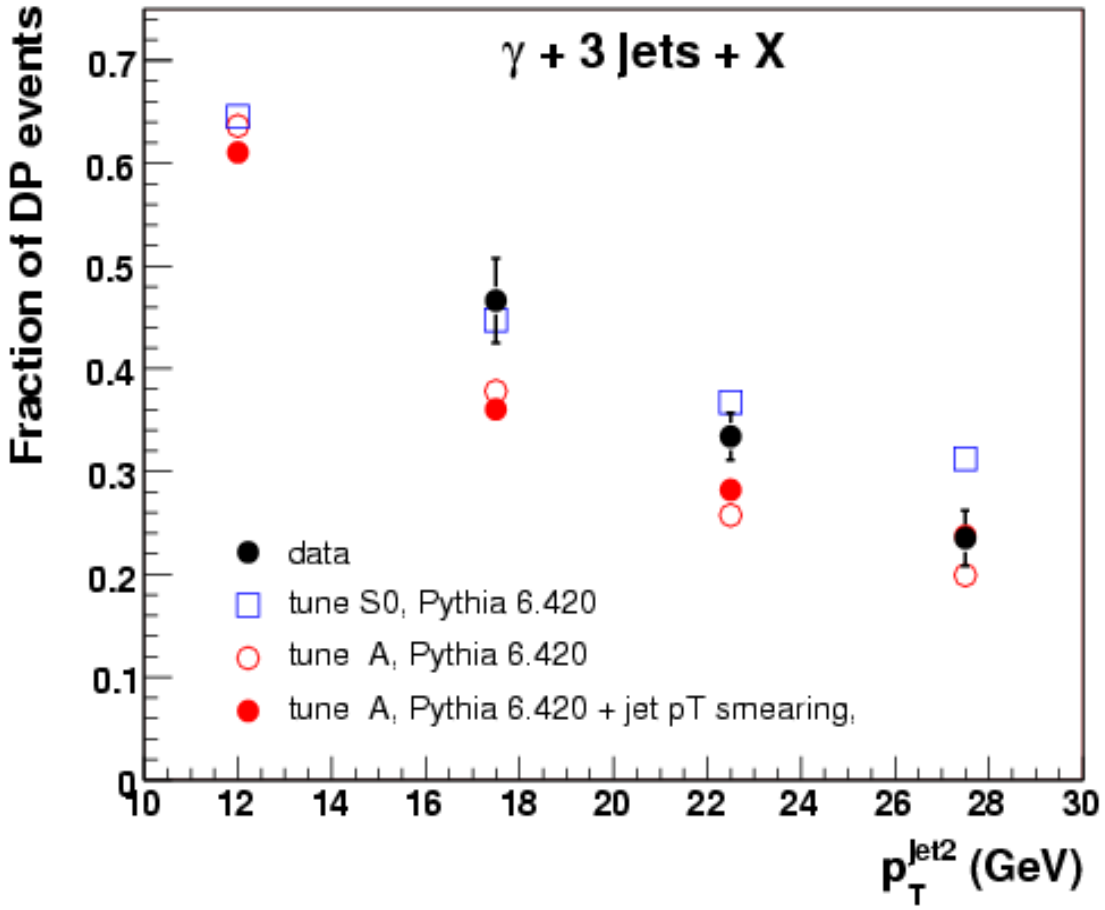




- Jet p_T from dijets falls much faster than that for radiation jets, i.e.

➔ Fraction of dijet (Double Parton) events should drop with increasing jet p_T
➔ Measurement is done in the three bins of 2nd jet p_T: 15-20, 20-25, 25-30 GeV

Fraction of DP Events



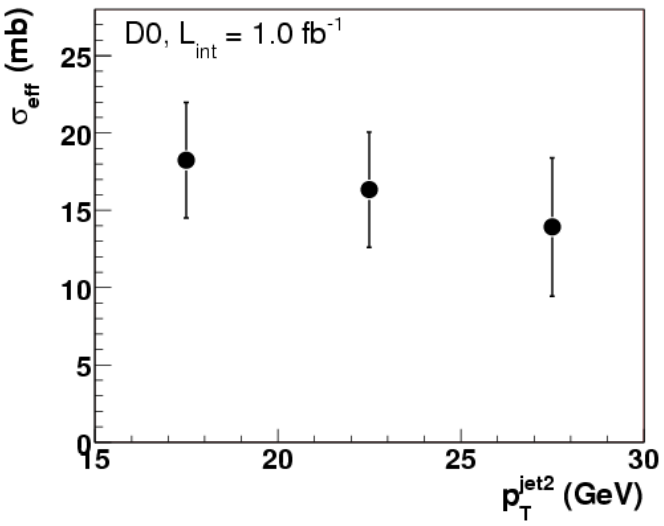
Pythia MPI tunes A and S0 are considered.

Data are in between the model predictions.

Data are not yet corrected to the particle level.

Will be done later to find the best MPI Tune

Calculation of σ_{eff}



σ_{eff} values in different jet p_T bins agree with each other within their uncertainties. (a slight fall can be also suggestive)

Uncertainties have very small correlations between jet2 p_T bins.

One can calculate the averaged (weighted by uncertainties) values over jet2 p_T bins:

$$\sigma_{eff}^{ave} = 16.4 \pm 0.3(stat) \pm 2.3(syst)\, mb$$

Main systematic and statistical uncertainties (in %) for σ_{eff}:

p_T^{jet2} (GeV)	Systematic uncertainty sources f_{DP}	f_{DI}	$\varepsilon_{DP}/\varepsilon_{DI}$	JES	$R_c\sigma_{hard}$	δ_{syst} (%)	δ_{stat} (%)	δ_{total} (%)
15 – 20	7.9	17.1	5.6	5.5	2.0	20.5	3.1	20.7
20 – 25	6.0	20.9	6.2	2.0	2.0	22.8	2.5	22.9
25 – 30	10.9	29.4	6.5	3.0	2.0	32.2	2.7	32.3

Conclusions

D0 Direct Diphoton Results

Measurements of single- and (first time) double-differential cross sections for direct diphoton production at $\sqrt{s}$=1.96 TeV with 4.2 fb^{-1}.

- Measurements are compared to state-of-art theoretical predictions such as DIPHOX and RESBOS, as well as PYTHIA (Comparisons with SHERPA have also been shown recently).
- None of the theoretical predictions fully describes the data in all kinematic regions of the four variables considered.

Photon + 3-jet Double Parton Results

- Have measured fraction of Double Parton events in three p_T bins of 2nd jet : 15-20, 20-25,25-30 GeV.

Varies from about 0.47 at 15-20 GeV to 0.22 at 25-30 GeV.

- Effective cross section (process-independent, defines rate of Double Parton events) measured in the same jet p_T bins with average value: σ_{eff} = 16.4 +/- 0.3 (stat) +/- 2.3 (syst) mb
- Double Parton production can be a significant background to many rare processes, especially with multi-jet final state.

Backup Slides

Direct Photon Predictions

- RESBOS, *Phys. Rev. D 76, 013009 (2007)* :
  - + Quark Scattering qqbar→γγ and Gluon Fusion gg→γγ up to ***NLO***
  - + Fragmentation at LO, with additional NLO approximation
  - + Resummation of soft/collinear terms of initial gluons up to all orders, cancelling divergence at NLO as $p_T(\gamma\gamma)\rightarrow 0$

- DIPHOX, *Eur. Phys. J. C 16, 311 (2000)* :
  - + qqbar→γγ up to **NLO** + gg→γγ at LO
  - + Fragmentation up to ***NLO***
  - + asymmetry di-photon $p_T(\gamma 1) > p_T(\gamma 2)$

- PYTHIA, *Comp. Phys. Comm. 135, 238(2001)* :
  - + qqbar→γγ and gg→γγ at LO
  - + Resummation via parton shower